Inventory and Monitoring of Coastal Erosion for Alaska's Arctic Network of Parks

OVERVIEW

There is an increasingly voiced perception among the public and within the scientific research community that pronounced coastal erosion in the Arctic is caused by global warming. There is solid inductive reasoning for this: reduced sea-ice concentrations, longer ice-free seasons leaving the coastline exposed to wave action, increased seasonal permafrost melting, rising sea level, etc. Unusually high rates of coastal erosion (documented for portions of the Arctic): are typically the greatest environmental concern for coastal communities; have impacts through release of sediment and organic carbon on neighboring nearshore ecosystems; lead to loss of coastal and freshwater habitats; represent an important indicator of environmental response to climate change; and consistitute some of the most rapid and most observable changes in Arctic ecosystems.

However, there is very little empirical evidence to demonstrate that coastal erosion is due to climate change *per se*. Indeed, taking a lesson from temperate latitudes, one should expect erosion – especially on barrier spits and islands – without any change in forcings. The limited data that exist at sufficiently high temporal resolution suggest that erosion is strongly controlled by the magnitude and frequency of extreme events (storms). For example, a preliminary analysis near Barrow indicates that as much as one-third of the erosion experienced over 49 years (see Fig. 1) occurred during a single storm, in 1963. Similar evidence exists from Tuktoyaktuk on the Canadian Beaufort Sea coast, for a short-lived but powerful storm in 1970. Coastal erosion does not appear to be gradually responding to monitonic Arctic warming. Instead, erosion appears to be filtered through the climatology of storms as the coupled land-sea-atmosphere system responds to changing boundary conditions. Thus, inventory and monitoring is required to quantify both the *temporal* and *spatial* variability in coastal erosion, and its impacts on ecosystems.
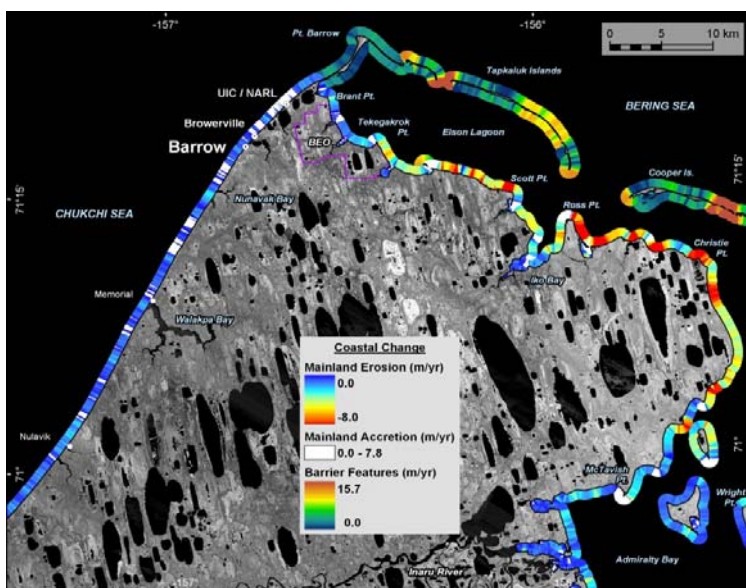

Figure 1. Orthorectified radar imagery from 2002 for the Barrow Pensinsula, showing erosion rates calculated by comparison with 1955 aerial photography (Manley, 2004). Coastal change is indicated by erosion (blue to red) or accretion (white). Nearly all coastal areas have experienced erosion, which is complex and spatially variable. Long-term average erosion rates reach up to 8 m per year.

COASTAL ECOSYSTEMS OF THE ARCTIC NETWORK

Coastal ecosystems within the Arctic Network (ARCN) comprise over 120 km and 250 km of shoreline, respectively, for Cape Krusenstern National Monument (CAKR) and Bering Land Bridge National Preserve (BELA). Including important bay and barrier island ecosystems surrounded by BELA, the extent of relevant shoreline ecosystems reaches approximately 450 km (Fig. 2). Coastal-influenced ecoystems include: lagoons with sand or gravel barrier spits and islands; sandy shores with low tundra bluffs; bays and inlets; and uncommon rocky shore and deltaic systems. These ecosystems, coupled with near-shore waters and adjacent terrestrial environments, provide habitat for a range of marine, freshwater, and terrestrial organisms. These ecosystems are impacted by a variety of drivers and stressors, including: human disturbance,
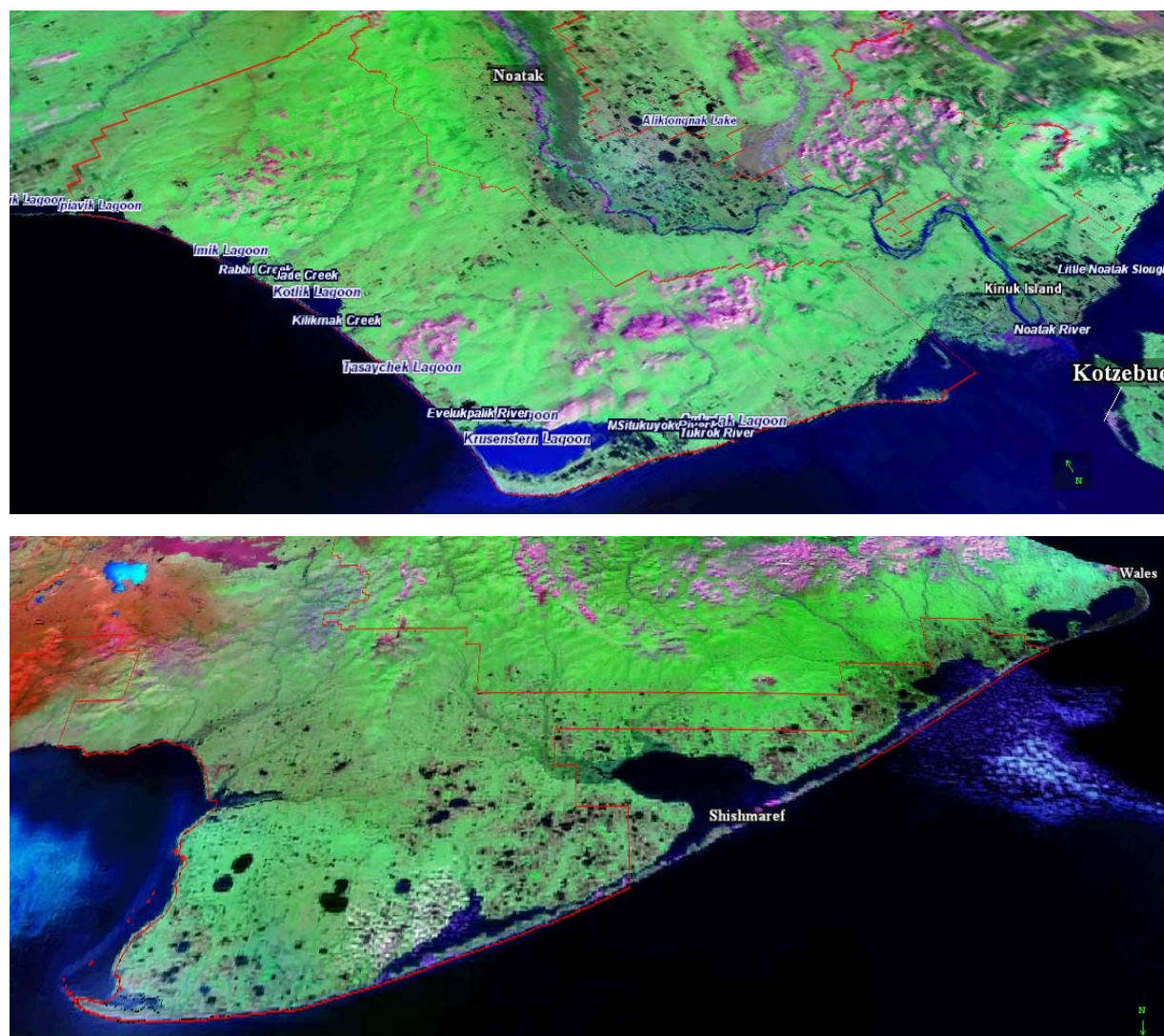

Fig. 2. Coastal ecosystems of the ARCN parks, as viewed through the perspective, fly-through environment of www.EarthSLOT.org. False-color Landsat7 imagery shows the diversity of coastal landform types for: A) Cape Krusenstern N.M. (upper, looking northeast) and Bering Land Bridge N.P. (lower, looking south).

sea-level rise, changes in sea ice concentration and duration, frequency and intensity of storms, and other factors related to climate change.

REMOTE SENSING AND GEOSPATIAL ANALYSIS

To comprehensively assess the temporal and spatial variability in shoreline change and related impacts, an inventory and monitoring program should take advantage of recently feasible methods based on Geographic Information Systems (GIS) and remote-sensing imagery. Studies of coastal erosion in the 1990's and earlier tended to focus efforts and results with point measurements at selected sites. However, advances in technology – and the availability of sufficiently high-resolution geospatial datasets, satellite imagery, and other remote sensing products – now makes it possible to economically and comprehensively quantify coastal erosion in space and time.

Such an approach requires well orthorectified, high-resolution base imagery and Digital Elevation Models (DEM's). For example, the acquisition of 1.25-m radar imagery and 5-m DEM's were required before a precise and comprehensive analysis could be undertaken in the Barrow area (Fig. 1; Lestak et al., 2004; Manley, 2004; Manley et al., 2004, 2005; Sturtevant et al., in press). High-resolution imagery (IFSAR radar imagery, Ikonos or QuickBird satellite imagery, or orthorectified aerial photography) is required for the quantification of erosion at rates of typically 0.1 to 10 m/yr. And high-resolution DEM's (from IFSAR or LIDAR) are required to calculate volumetric loss or gain, as well as sediment and carbon fluxes to nearshore marine ecosystems. The orthorectified base imagery fundamentally provides a "reference frame" for the georectification and co-registration of historic aerial photography. Georectification thus enables co-registration of the image timeslices, such that one year of imagery directly overlies another year's imagery. Thus, the first step for comprehensive inventory and monitoring of coastal erosion is the acquisition of high-resolution imagery and DEM's.

Thereafter, quantification and analysis of erosion rates can begin using recently developed procedures within standard GIS and remote sensing packages. The shoreline is digitized at intervals of ca. 20 m on the base imagery. Similarly, past shoreline positions are digitized for available years of aerial photography. Stepwise quantification with vector and raster algorithms results in maps and data describing erosion rates, change in erosion rate through time, areas lost and gained, volumes lost and gained, and fluxes. Spatial and temporal patterns can be related to land cover classes and other environmental variables (nearshore bathymetry, fetch, coastal angle, bluff height, surficial geology, thaw-lake density, etc.). Patterns can also be evaluated relative to coastal geomorphic type and other descriptive classifications. In this way, interpretive analysis can clarify: environmental controls on erosion rate and related processes; ecosystem response to drivers & stressors; and impacts on coastal habitat and associated ecosystem components.

Phase 1: Acquisition and Processing of Imagery and DEM's

CAKR and BELA currently lack the required high-resolution orthorectified imagery and DEM's. Thus, the first step toward analysis will involve the coordination, acquisition, and quality review of high-resolution base imagery (Ikonos, QuickBird, IFSAR, or OrthoPhoto Mosaics) and DEM's (IFSAR or LIDAR). This step by itself requires a substantial amount of oversight. At

the same time, historic aerial photography can be purchased and scanned. Once the base imagery has been reviewed and accepted, the historic photography can be georectified using image-to-image registration in GIS and Remote Sensing packages such as ArcGIS and ERDAS Imagine. Georectification includes time-consuming manual procedures for establishing visual ground control links, and calculating RMSE spatial errors with independent check points.

For planning purposes, a number of options were considered for base imagery. Ikonos satellite imagery can not be adequately orthorectified with existing DEM's. IFSAR is beyond the scope of the budget. Luckily, the NPS and NOAA had acquired aerial photography for the study's Area of Interest (AOI) in 2003 (Fig. 3; natural color at a scale of 1:24,000). The photography was acquired by AeroMap US with sufficient onboard georeferencing information (IMU and airborne Differential GPS) such that it can be orthorectified with little or no ground control. The stereo imagery can be orthorectified without an independently derived DEM. As planned with an initial estimate from AeroMap, the resulting OrthoPhoto Mosaic will have a horizontal resolution of 0.5 m, which is more than adequate (and at a higher resolution than possible currently with commercial satellite imagery). AeroMap will be subcontracted to create and deliver the OrthoPhoto Mosaic. Specifications to be resolved with a final estimate include: licensing, horizontal accuracy, scratch removal, and detailed extent of the final product.
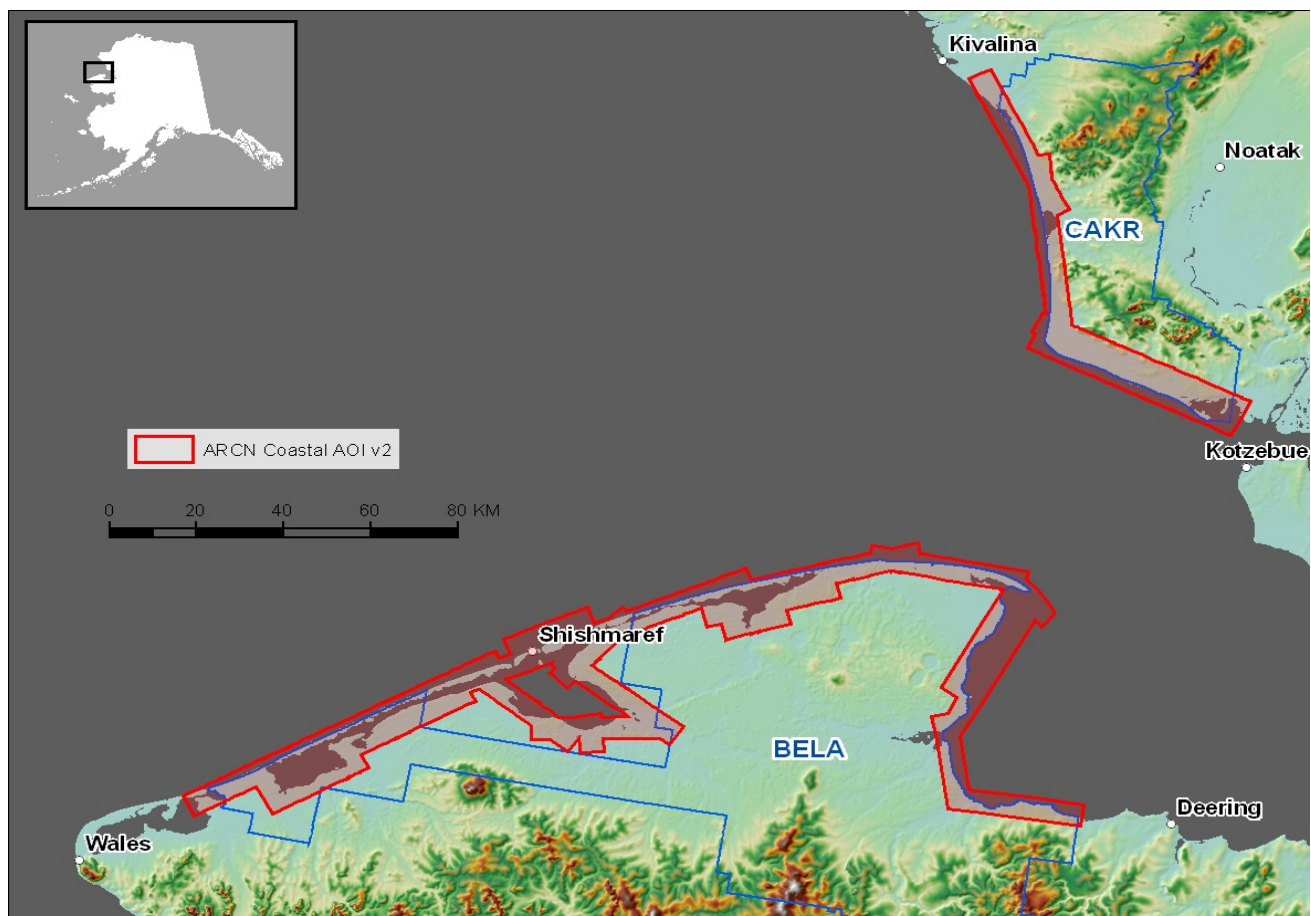

Fig. 3. Extent of the 2003 NOAA and NPS aerial photography (in red), establishing the Area of Interest (AOI) for the OrthoPhoto Mosaic and analysis of coastal erosion.

A number of options were also considered for a DEM. IFSAR was too expensive, and existing USGS DEM's are too poorly resolved to be of use for volumetric calculations and related spatial analyses. Luckily, NOAA paid for AeroMetric acquisition of a LIDAR DEM in 2003. This DEM covers most or all of the AOI, except that it is limited to a narrow strip within approximately 1 or 2 km of the outermost coastline. NOAA has agreed to share the data with the NPS at minimal cost for distribution. The LIDAR DEM is currently under production, will be available soon, and will have more than adequate horizontal resolution, horizontal accuracy, and vertical accuracy for the objectives outlined here.

To augment the 2003 OrthoPhoto Mosaic for calculation of erosion rates, sets of historic aerial photography at adequate resolution will be purchased and scanned. At this time it appears that available photography for the AOI includes early 1950's black and white imagery, mid 1980's AHAP Color Infrared frames, and possibly 1999 photography. The characteristics and extent of historic photography will be inventoried early during Phase 1.

It is quite likely also that Ikonos or similar satellite imagery will be collected in 2005, as coordinated through NPS AKSO. This imagery will be georectified to the 2003 OrthoPhoto Mosaic to yield an additional time slice for analysis.

The detailed OrthoPhoto Mosaic and coregistered sets of imagery will provide a valuable resource beyond the scope of this study. For use by NPS and partner investigators, and open to the public through a general license, the imagery and geospatial data will facilitate a range of inter-disciplinary and multidisciplinary investigations on ecosystem change.

Phase 2: Spatial Analysis and Interpretation

The remote-sensing approach for study of coastal erosion enables the significant advantage that we can conduct both inventory and monitoring. For example, the coastline will be digitized as apparent in the well-resolved 2003 OrthoPhoto Mosaic, establishing a temporal baseline as an "inventory". In addition, the availability of historic photography makes it possible to "monitor" or track coastal change into the past. Coastlines will be digitized for the early 1950's, mid 1980's, possibly 1999, and possibly 2005. Raster and vector analysis will then calculate erosion rate for the intervening time periods, as well as aerial and volumetric loss or gain, and fluxes across the land-sea interface. As described above, we will then interpret (and in some cases quantify) relationships with various environmental variables, processes, drivers, and stressors. In this way, the coastal ecosystems of CAKR and BELA can be comprehensively inventoried and monitored in both space and time.

NPS INVOLVEMENT

The NPS agrees to:
     1. Provide financial assistance to the University of Colorado at Boulder (CU) as stated in this agreement. Additionally NPS will cover travel costs for CU principal investigators and staff (if necessary beyond the contract budget to complete the project).
     2. Assist CU in the planning, development and implementation of the project. Provide scientific expertise for content, management and organization of the project.

3. Participate in face-to-face meetings and teleconferences on a semi-regular basis. Updates of progress and input by NPS personnel will occur throughout the duration of the project.

4. Provide CU project leaders and staff with guidance on technical report specifications.

5. Provide existing aerial photography, other imagery, and geospatial datasets (especially from AKSO) as available and contingent on existing license agreements.

TIMELINE AND DELIVERABLES

Phase 1 (Year 1, 7/2005 – 6/2006)

Science Plan:
- As needed, revise the objectives, scope, and approach as outlined in this scope of work, with input from NPS officials on planning and implementation.
- Produce semi-annual progress reports.

Orthophoto Mosaic:
- Obtain final estimate and negotiate subcontract with AeroMap US for the 2003 OrthoPhoto Mosaic.
- Obtain written authorization from NOAA for use through licensing of the NOAA 2003 photography and LIDAR DEM.
- Obtain the NPS and NOAA photography and LIDAR DEM's; deliver to AeroMap for creation of the OrthoPhoto Mosaic.
- Coordinate with AeroMap for creation of the OrthoPhoto Mosaic.
- Receive and evaluate the OrthoPhoto Mosaic for accuracy and other specifications, with possible revision.

Historic Photography:
- Coordinate with NPS AKSO, AeroMap, NOAA, USGS, and other agencies to build a database of relevant historic photography (coverage, scale, priority, licensing, etc.).
- Purchase or borrow prints, negatives, or scans of the photography, within the limits of the budget and subject to licensing agreements.
- Using a large format scanner, scan the prints or negatives at 1200 dpi or better for anticipated horizontal resolution of 1.5 m or better.

Georectification:
- After the base imagery has been reviewed and accepted, georectify each frame of the aerial photography using polynomial image-to-image registration with a sufficient number of control links (commonly identifiable visual features) per frame.
- Through use of independent check points on each frame, quantify the RMSE spatial error for co-registration.

Deliverables:
- If needed, a revised Science Plan.
- Semi-annual progress reports
- Copy of the NOAA LIDAR DEM

- Evaluated and approved 2003 OrthoPhoto Mosaic, with a QC evaluation report and other metadata.
- Georectified historic aerial photography with metadata
- Summary report for Phase 1

Phase 1 (Year 1, 7/2006 – 6/2007)

Science Plan:
- As needed, revise the objectives, scope, and approach outlined above with input from NPS officials on planning and implementation.
- Produce semi-annual progress reports.

Geospatial Processing:
- Refine a quality system for processing, data handling, file naming conventions, backup, etc.
- Refine and test GIS vector and raster algorithms ("scripts") for spatial analysis.
- Evaluate selected focus areas for prioritized completion of analysis, if necessary
- Digitize the 2003 shoreline.
- Digitize shorelines for other years of georectified imagery.
- Conduct spatial analysis with stepwise scripts to calculate erosion rate, area lost and gained, volume lost and gained, and fluxes to the nearshore marine ecosystem.
- Error analysis.
- Create metadata for the resultant geospatial datasets.

Interpretive Analysis:
- Derive environmental variables such as coastal angle, bluff height, and other factors from the LIDAR DEM
- Assemble and process other environmental spatial datasets such as land cover class, thaw-lake density, and other factors, as available.
- Assemble a database on historic synoptic climatology as related to strong wind events and sea ice.
- Through quantitative and qualitative analysis, evaluate relationships between the environmental variables and erosion rate, in both space and time.

Report Preparation:
- Prepare maps, tabulated data, graphs, animations, and other types of presentation materials.
- Prepare a final report documenting objectives, background, methods, results, and interpretation for the purposes of inventory and monitoring.

Deliverables:
- If needed, a revised Science Plan.
- Semi-annual progress reports.
- Vector and raster geospatial datasets (GIS layers such as the coastline shapefiles and derived layers) with metadata.
- Maps, tabulated data, graphs, animations, and other types of presentation materials (in electronic format when feasible)

- Final report

With nearly 500 km of coastal ecosystems, the products above will require substantial coordination, acquisition, and processing for a fully comprehensive spatial analysis. It may be necessary, given resource constraints, to focus on selected portions of the CAKR and BELA shorelines. This is particularly true if available photography enables a higher degree of temporal resolution for selected areas.

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